INQUIRY & INVESTIGATION

Integrating Quantitative Skills in Introductory Ecology: Investigations of Wild Bird Feeding Preferences

RECOMMENDED FOR AP Biology

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Abstract

Undergraduate biology education is undergoing dramatic changes, emphasizing student training in the "tools and practices" of science, particularly quantitative and problem-solving skills. We redesigned a freshman ecology lab to emphasize the importance of scientific inquiry and quantitative reasoning in biology. This multi-week investigation uses observations of avian form and function and an extensive student-generated data set to introduce hypothesis testing, experimental design, and biological statistics. Research groups compare feeding preferences (location and seed selection) between selected species of wild birds, evaluating their findings quantitatively through descriptive statistics, graphing, and data analysis, and ecologically through comparisons of species biology and natural history.

Key Words: *Undergraduate biology education; ecology laboratory; supplementary bird feeding; statistics; chi-square.*

Research on learning, student feedback and classroom assessments, and criticisms from scientific researchers and professionals have inspired dramatic changes in undergraduate biology education (D'Avanzo, 2003; AAAS, 2011). Central to this change is "scientific teaching" and the development of "biological literacy," whereby students gain biological competencies by *doing science* rather than memorizing large bodies of facts (Handelsman et al., 2004; AAAS, 2011). Undergraduate biology increasingly involves students in original research, integrates quantitative skills, and works to bring these elements into the everyday classroom. Students develop research questions, deliberate on methods to address these questions, troubleshoot and conduct laboratory and field investigations, and evaluate results quantitatively and holistically, making basic mathematical and statistical competencies essential to modern scientific training (Bialek & Botstein, 2004; AAAS, 2011).

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Introducing students to the quantitative, problem-solving nature of science early in their undergraduate education and making explicit links between biology and mathematics is considered vital in effectively preparing future science educators, researchers, and professionals (National Research Council, 2003; AAAS, 2011; Goldstein and Flynn, 2011). However, undergraduate biology students traditionally have been taught quantitative skills in isolation, through separate math and statistics courses. We redesigned an existing, largely observation-based ecology lab to enhance these connections and build quantitative competencies in freshman biology majors (Biology 131: Ecology & Adaptation, Radford University). This multi-week investigation uses observations of bird form and function and data collected on feeding behaviors of wild birds to introduce hypothesis testing and applied statistics and to emphasize the critical role of quantitative thinking. Students generate and test hypotheses about feeding preferences using an extensive class-generated data set and formulate plausible explanations based on species biology. Our goal is to introduce analytical skills early and often in our undergraduate biology curriculum and to further connections between math and biology and between biological content and practice.

○ Project Preparation

Introducing Biological Statistics

In our general ecology course, we introduce statistics and experimental design by asking: What is statistics? How are statistics used in evaluating ecological questions? What is statistical or biological significance?

Students work in groups to identify variables, state hypotheses, and select appropriate graphs and statistical tests for sample research questions (Table 1). For example: "Is grasshopper density higher in grasslands than in forests?" The independent variable is habitat type (categorical); the dependent variable is grasshopper density (numerical). Students select and sketch a bar graph, labeling axes and sketching plausible data, and select t-test as the statistical test. This procedure is repeated in lab investigations throughout the

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Table 1. Selection of common graphs and statistical tests based on independent and dependent variable classifications.[a]

Independent Variable	Dependent Variable	Graph Type	Statistical Test
Numerical	Numerical	Scatter	Regression or correlation
Categorical	Numerical (means)	Bar (mean ± standard error)	t-test or ANOVA
Categorical	Categorical (percents or totals)	Bar	Chi-square test

[a] Summary table modified from an undergraduate ecology handout by F. Singer, Radford University.

semester (for an excellent overview of common statistical tests and sample analyses, see McDonald, 2009).

Set-Up

Two weeks before student observations begin, we set up bird feeders on our university campus. Ideal locations offer tree or shrub cover and limited foot traffic. We use three hanging feeders, each with separate columns for three different seed types, plus two hanging suet cages. Feeders are filled with sunflower, thistle, and millet to offer different seed sizes and nutritional qualities, and mixed seeds are scattered on the ground beneath each feeder. Feeders are checked and refilled each week.

Pre-Lab Assignments

One week in advance, we assign a review article that describes potential benefits and negative effects of supplemental bird feeding. Two articles that we have found particularly effective in generating student discussion are Jones & Reynolds (2008) and Robb et al. (2008). Students also are provided with photographs of 15 common bird species to learn to identify by sight.

○ Lab 1: Hypothesizing about Form & Function

This 3-hour lab begins with a bird identification quiz and brief article discussion (~20 minutes) in which students describe pros and cons of feeding wild birds. In the remaining lab time, they explore the diversity of body sizes and beak shapes in wild bird species and consider implications for feeding behaviors.

Mini-Activity 1: Nutritional content of wild bird foods. In small groups, students compare millet, thistle, and sunflower seeds and a small piece of suet. Given the typical fat content of each food item (suet: 94%, sunflower: 43%, thistle: 40%, millet: 4%; National Bird-Feeding Society, http://www.birdfeeding.org/), students weigh and calculate milligrams of fat for each food.

Mini-Activity 2: Variations in beak and body sizes. Student groups examine museum specimens of common bird species for differences in body and beak size and shape. (Photographs and species descriptions also may be used.) Our specimens range in body size from relatively large (American crow, hairy woodpecker, blue jay) to small (American goldfinch, black-capped chickadee) and in beak shape from short and conical (northern cardinal, house finch) to relatively long and narrow (white-breasted nuthatch, hairy woodpecker).

Students construct a table summarizing their observations and develop hypotheses and plausible explanations for predicted feeding behaviors (e.g., tradeoffs associated with seed size, hardness, and nutritional content vs. body size and beak size/shape). Students typically relate energetic demands to body size by suggesting that larger birds are likely to eat suet and/or larger seeds. They often predict that thicker beaks allow birds to crack larger seeds such as sunflower more effectively but may hamper manipulation of tiny seeds. Conversely, tiny-beaked birds may have difficulty with sunflower seeds but feed efficiently on thistle. Because millet is relatively small and low in fat, students often suggest that it will have few visits. Additionally, differences between hanging feeders and suet cages are commonly noted, leading to comparisons of toe arrangements in perching birds (one backward, three forward) versus woodpeckers (two backward, two forward). These ideas lead readily to discussions of evolution, interspecific competition, and niche partitioning (e.g., selective pressures for beak shape relative to food availability), supporting central class concepts (for discussion of beak size and "bite force" in relation to feeding efficiency, see Diaz [1990] and van der Meij & Bout [2006]; for classic studies of evolution in Darwin's finches, see Grant [1986]).

Project Overview

We conclude Lab 1 with a brief sample observation session (15–20 minutes) at the bird feeders, reviewing species identification, feeder set-up, and bird-watching procedures. As a class, we develop research questions, specific observational procedures, and a data sheet (Figure 1) and establish research groups of two or three students for the multi-week project. Through guided discussion, students selected the following research questions for investigation:

Question no. 1: Do bird species differ in their food preference? (hanging feeders only)

Question no. 2: Do bird species differ in their feeding location? (hanging vs. ground feeder)

○ Lab 2: Observing Feeding Behaviors

During the second week, each student group works independently to collect feeding data during eight 30-minute observation sessions. Students identify each species and note its feeding location and selection. For logistical ease, we do not prevent groups from collecting data simultaneously. Thus, some feeding events may be recorded by more than one group. (In advanced classes, students could be asked to design field methods that prevent duplicate observations.) Groups enter their data on the course webpage before Lab 3. Instructors are available as needed throughout the week.

○ Lab 3: Analyzing Bird Feeding Observations

Our third lab reviews scientific graphing, data summary, and analytical procedures. We use an MS Excel spreadsheet with hypothetical feeding data for two bird species to review research questions,

Date:	Start time:		End time:		
Temperature:	Weather Conditions:				
Bird Species	HANGING FEEDERS				GROUND
	Sunflower	Thistle	Millet	Suet	
Other observations (interactions, aggression, feeding behaviors, weather-related behaviors, etc.):					

Figure 1. Student data sheet for recording observations of bird feeding behaviors and ambient conditions.

Table 2. Bird feeding data collected by 75 students in Biology 131, Ecology & Adaptation, at Radford University in spring 2011.

	Hanging Feeders				
Bird Species	**Sunflower**	**Thistle**	**Millet**	**Suet**	**Ground**
House finch	365	186	92	46	434
American goldfinch	250	360	98	40	106
Sparrow	241	55	209	7	732
Tufted titmouse	229	39	47	20	87
Northern cardinal	185	8	14	9	275
Black-capped chickadee	157	77	94	29	170
Blue jay	125	15	11	96	258
White-breasted nuthatch	125	6	2	106	36
Mourning dove	40	31	18	0	454
Hairy woodpecker	39	3	8	86	7
Dark-eyed junco	32	41	51	5	378
Red-bellied woodpecker	20	2	5	51	4
American robin	14	6	15	9	155

Notes: Values represent number of observed feeding events (seeds taken or suet feeding visits) across all research groups. European starlings and American crows were excluded because of insufficient numbers of observations.

discuss graphing guidelines (e.g., axis scaling, titles, units, figure captions), and construct a 100% stacked bar graph comparing ground versus hanging feeder visits across species (research question no. 2). Students determine that a chi-square test (test of independence; McDonald, 2009) is most appropriate for analyzing this comparison. (Students used this test once before, completing calculations by hand.) We review this test and use Excel to introduce spreadsheet formulas and manipulation of large data sets. For additional practice, groups repeat this process, graphing and analyzing hypothetical seed-preference data across the two species (research question no. 1). We conclude by introducing the large class data set (7,046 feeding observations). After a brief introduction to statistical "assumptions," particularly sample-size requirements for chi-square (minimum expected values ≥5; McDonald, 2009), students determine that starlings and crows should be excluded from analysis. The resulting data set contains 6915 observations (Table 2). Each group selects two species for comparison, and we discuss analysis and report requirements.

○ Lab 4: Project Report

The fourth week provides time for student groups to work independently on data analysis and research reports. Instructors are available throughout the week, and students may submit reports in advance for ungraded feedback. Required report components are (1) informative title; (2) introduction defining research questions (investigating food preferences and feeding locations, as described above), hypotheses, and variables; (3) species natural history (description, geographic range, habitats, diet, behavior, and conservation status; sources: All About Birds, http://www.allaboutbirds.org; Animal Diversity Web, http://animaldiversity.ummz.umich.edu); (4) data collection methods; (5) graphs and statistical results for both research questions; and (6) discussion. This final section asks students to interpret their results in relation to the natural-history information they gathered for their two species (Figures 2 and 3 and Table 3).

○ Discussion

Feeding of wild birds offers a wealth of opportunities for ecological research and student-centered learning. It is familiar and enjoyable, and many students delight in gaining identification skills. In addition, supplementary feeding has been described as a "driver of ecological change," increasing clutch sizes, fledgling success, and species ranges; altering competitive interactions, predation, and disease risk; and increasing reliance on human-supplied foods (Jones & Reynolds, 2008; Robb et al., 2008). These issues contribute to

Research question 1: Do cardinals and blue jays differ in their food preference?
Independent variable: Bird species (categorical)
Dependent variable: Food type (categorical)
Graph: Bar graph
Statistical test: Chi-square test

We used a chi-square test of independence to evaluate H_o: cardinals and blue jays do not differ in their food preferences (proportion of visits to sunflower, millet, thistle, or suet). Observed numbers of visits were used to calculate visits expected for each food type (Table 3). For example, expected feeding visits for cardinals on sunflower: (no. of cardinal visits) × (no. of sunflower visits) / (total no. of visits) = (216 × 310) / 463 = 144.6. We repeated this procedure for each species and food combination. Our chi-square test statistic was calculated as follows:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$, where O = observed, E = expected.

Degrees of freedom = (no. of rows –1) × (no. of columns –1) = (2 –1) × (4 –1) = 3.

Because χ^2 calculated was greater than χ^2 critical, we rejected H_o and concluded that these species differ in seed preference. Cardinals fed mostly on sunflower. Blue jays fed nearly equally on sunflower and suet. Neither fed often on thistle or millet (Figure 3). In natural settings, blue jays are omnivores, feeding on seeds and soft, fat-rich foods including eggs, insects, frogs, and mice (Frysinger, 2001), whereas cardinals feed mostly on seeds (90% of diet; Crane, 2001). This may explain the greater suet-feeding we observed in blue jays.

Figure 2. Excerpt from student analysis.

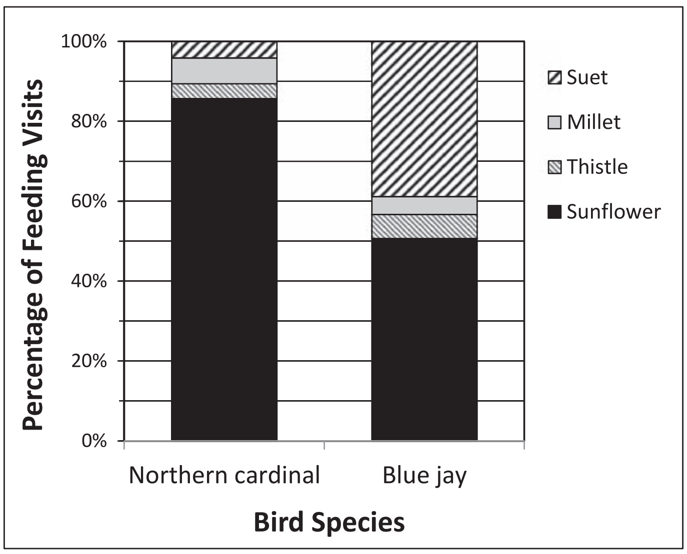

Figure 3. Comparison of food preferences for northern cardinals (n = 216) and blue jays (n = 247), based on the percentage of visits to each food type. Observations made in February 2012 from two suet and three seed feeders on the Radford University campus. These species differed in their feeding preferences ($\chi^2_{calculated}$ = 84.5 versus $\chi^2_{critical}$ = 7.81, df = 3), with cardinals most often selecting sunflower seeds and blue jays selecting both sunflower and suet.

Table 3. Chi-square observed, expected, and calculated values used to compare food preferences between northern cardinals and blue jays.

	Sunflower	Thistle	Millet	Suet	Total
Observed Values					
Northern cardinal	185	8	14	9	216
Blue jay	125	15	11	96	247
Total	310	23	25	105	463
Expected Values					
Northern cardinal	144.6	10.7	11.7	49.0	
Blue jay	165.4	12.3	13.3	56.0	
Calculated Values					
Northern cardinal	11.3	0.7	0.5	32.6	
Blue jay	9.9	0.6	0.4	28.5	
χ^2 calculated value = 84.5, χ^2 critical value = 7.81, df = 3					

the ecological scope and overall relevance of this project. Outdoor experiences also have been found to enhance attention skills and reduce behavioral issues associated with "nature deficit disorder," the growing disconnection between American children and outdoor/nature activities (Faber Taylor et al., 2001; Louv, 2005).

With limited budgets and increased enrollments, labs such as these can be advantageous in that they require minimal cost and space and can be used by large numbers of students (Sundberg et al., 2005). We used this sequence in undergraduate introductory ecology, but these activities could be adapted for K–12 science. In addition, this sequence easily accommodates experimental variations and more sophisticated analysis. In advanced courses, literature or discussions of optimal foraging, competitive interactions, antipredator or social behaviors, metabolism and body scaling, and other biological or conservation topics could be incorporated. This data set can be used to address additional research questions or other quantitative or statistical skills. For example, students might calculate bird diversity measures at different food sources. They might ask whether body size affects food choice (ANOVA comparing mean body or bill size across seed types), if body size can be used to predict food consumption (regression of fat consumption [calculated from numbers and types of seeds eaten] on species body mass), or compare seed husking rates for their selected species (t-test). We plan to reexamine the experimental design and analysis used here in a new biostatistics course, to enhance connections between biology and mathematics in our curriculum.

Lab experiences are vital to undergraduate biology education, particularly investigations that train students in the "tools and practices" of science (Handelsman et al., 2004; AAAS, 2011). Here, students collected data from living organisms, evaluated their data for quantitative patterns, and developed biological interpretations for these patterns. This revised sequence required several weeks of our freshman ecology lab. However, our approach provided time to guide first-semester biology majors in developing research questions and data-collection techniques and to collaborate with fellow students to analyze and interpret data and practice scientific writing skills. This repeated exposure to scientific inquiry and statistical applications, particularly early in undergraduate biology education, has been shown to increase interest in learning and enhance problem-solving skills and quantitative competencies (Bialek & Botstein, 2004; Handelsman et al., 2004; Speth et al., 2010). Thus, our modified lab sequence provides students with repeated exposure and increasing independence in manipulating and summarizing data, conducting and interpreting statistical analyses, and justifying conclusions quantitatively and biologically. This emphasis on the central importance of quantitative thinking in biology should help to train undergraduate biology students more effectively in the process of science.

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